GEOTECHNICAL PERFORMANCE USING ALKALINE ACTIVATED FLY ASH FOR SOIL MIXTURES WITH AND WITHOUT POLYPROPYLENE FIBERS

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I would like to dedicate this thesis to
my beloved FATHER and MOTHER
my WIFE and my CHILDREN
my SISTER and BROTHERS

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ABSTRACT

Soil stabilization is one of the well-known methods to treat problematic soils. Its advantages over soil replacement are that of low cost and fast implementation. Alkaline activation (geopolymerezation) of soft soils is a new technique that has been addressed recently to stabilize soft soils. Though it's strengthening mechanism and final product in terms of stiffness and brittleness resembles that observed by cemented soils. In other words, the residual strength emerged when approaching failure is very low resulting in immediate damage of building structures. Therefore, the aforesaid shortcoming needs to be overcome particularly when horizontal displacement is present. In this regard, Potassium hydroxide was added to a mix of fly ash class F and polypropylene fibers to stabilize and reinforce Kaolin clay (S1) and marine clay (S2) respectively. The fly ash solid ratio was considered to be 10%, 20%, 30%, 40%, while polypropylene fiber proportions adapted for the study were 0.5%, 0.75%, 1% 1.25%. Compressive-, flexural- and indirect tensile tests as well as California bearing capacity (CBR)- & one dimensional consolidation tests were conducted. The compressive strength results of 28 days curing regime confirm the 40% fly ash mixture to contribute to the sharpest increase in compressive strength at 3680, 6980 kPa respectively. Though a sharp drop was observed. With the inclusion of polypropylene fibers, the mode of failure changed to a more ductile one resulting in peak strength values at 6450 kPa and 5834 kPa respectively. Besides, flexural and indirect tensile results were recorded to be 1555, 1770, 1833, 1819, 1541, 1777, 1545 and 1440 kPa for S1F40, S1FR0.75, S2F40 and S2FR0.75 respectively. In addition, the incorporation of fly ash and polypropylene fibers increased the CBR values of all pretreated mixtures indicating values of 51.2%, 69.8%, 48.1% and 59% for S1F40, S1FR0.75, S2F40 and S2FR0.75 respectively. Finally, the compression index and the preconsolidation pressure exhibited a substantial decrease and increase at 0.043,

0.076, 0.047, 0.104 and 900 kPa, 400 kPa, 500 kPa, 240 kPa for S1F40, S1FR0.75, S2F40 and S2FR0.75 respectively. It is to conclude, that the proposed new technique has a promising future to be used in soil stabilization domain where horizontal displacement is expected.

ABSTRAK

Penstabilan tanah merupakan salah satu kaedah yang terkenal digunakan untuk merawat tanah bermasalah. Kelebihannya ke atas kaedah penggantian tanah adalah dari segi kos yang rendah dan pelaksanaan yang cepat. Pengaktifan beralkali (*geopolimerization*) tanah lembut merupakan teknik baharu untuk menstabilkan tanah lembut. Walaupun, mekanisma pengukuhan dan produk akhir dari segi kekerasan dan kerapuhan menyerupai apa yang diperhatikan pada tanah yang dikukuhkan. Dalam kata lain, kekuatan lebihan yang terhasil adalah rendah semasa menghampiri kegagalan mengakibatkan kerosakan serta-merta pada struktur bangunan. Oleh yang demikian, kelemahan yang disebutkan di atas perlu diatasi terutamanya apabila terdapat kehadiran pergerakan mendatar. Sehubungan dengan itu, Potassium Hidroksida telah ditambah kepada campuran abu terbang kelas F dan gentian polipropilena untuk menstabilkan dan memperkukuhkan tanah liat Kaolin (S1) dan tanah liat marin (S2). Nisbah pepejal abu terbang yang dipertimbangkan adalah 10%, 20%, 30% dan 40%, manakala perkadaran gentian polipropilena yang disesuaikan untuk kajian ini adalah 0.5%, 0.75% 1% dan 1.25%. Ujian mampatan, lenturan dan tegangan tidak langsung serta ujian nisbah galas *California* (CBR) dan pengukuhan satu-dimensi telah dijalankan dalam kajian ini. Keputusan kekuatan mampatan daripada pengawetan selama 28 hari mengesahkan campuran 40% abu terbang menyumbang kepada peningkatan kekuatan mampatan yang paling ketara iaitu 3680 kPa dan 6980 kPa. Namun begitu, kejatuhan mendadak turut diperhatikan. Dengan penambahan gentian polipropilena, mod kegagalan bertukar menjadi lebih lentur dan hasilnya nilai kekuatan puncak menjadi 6450 kPa dan 5834 kPa. Selain itu, keputusan ujian lenturan dan tegangan tidak langsung merekodkan nilai 1555, 1770, 1833, 1819, 1541, 1777, 1545 dan 1440 kPa masing-masing bagi sampel S1F40, S1FR0.75, S2F40 dan S2FR0.75. Di samping itu, campuran abu terbang dan

gentian polipropilena meningkatkan nilai CBR semua sampel terawat iaitu 51.2%, 69.8%, 48.1% dan 59% masing-masing untuk sampel S1F40, S1FR0.75, S2F40 dan S2FR0.75. Akhir sekali, indeks pemampatan tanah dan tekanan pra-pengukuhan menunjukkan penurunan dan kenaikan yang ketara iaitu 0.043, 0.076, 0.047 dan 0.104 bagi 900 kPa, 400 kPa, 500 kPa dan 240 kPa masing-masing untuk sampel S1F40, S1FR0.75, S2F40 dan S2FR0.75. Ia menyimpulkan bahawa teknik baharu yang dicadangkan mempunyai potensi untuk digunakan bagi penstabilan tanah di mana pergerakan mendatar adalah dijangka.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

µm	-	Micrometer
C°	-	Celsius degree
AAG	-	Alkali activated grout
AAS	-	Alkali activated soil
Al	-	Aluminum
Al_2O_3	-	Aluminum oxide
A/S	-	Activator solid ratio
As_2O_3	-	Diarsenic trioxide
A-S-H	-	Aluminum silicate hydrate
ASTM	-	American society for testing and material
BaO	-	Barium oxide
BFA	-	Badarpur fly ash
BS	-	British standard
BTS	-	Brazilian tensile test
C	-	Carbon
C 1, 3, 7 %	-	Cement content in respect to solid
Ca++	-	Calcium ion
$(Ca_6Al_2(SO_4)_3(OH)_{12}{\bullet}26H_2O)$	–	Ettringite
$CaCO_3$	-	Calcium carbonate
C-A-H	-	Calcium aluminum hydrate
CaO	-	Calcium oxide
$Ca(OH)_2$	-	Calcium hydroxide
CPB	-	Cemented paste backfill
CBR	-	California bearing capacity
Cc	-	Compression index

CEC	-	Cation exchange capacity
CH	-	High plasticity clay
CH_3	-	Hydrocarbon, Methyl group
CL	-	Low plasticity clay
Cm^2/g	-	Unit of fly ash specific area
CO_2	-	Carbon dioxide
CO^{-3}	-	Carbonate ion
CSH	-	Calcium silicate hydrate
CuO	-	Copper oxide
Cv	-	Coefficient of consolidation
D	-	Specimen diameter
d	-	Day
E	-	Young’s modulus
EDS	-	Energy dispersive x-ray spectrometry
FA	-	Fly ash
Fe	-	Iron
Fe_2O_3	-	Ferric oxide
FRC	-	Fiber reinforced concrete
FRS	-	Fiber reinforced soil
FS	-	Flexural strength
FTIR	-	Fourier transform infrared spectroscopy
Ga_2O_3	-	Gallium Oxide
GGBS	-	Ground granulated blast- furnace slag
Gpa	-	Giga pascal
H	-	Hydrogen
h	-	hour
H_2O	-	Water
K	-	Potassium
KBr	-	Potassium bromide
Kg	-	Kilogram
K_2O	-	Potassium oxide
KOH	-	Potassium hydroxide

KN	-	Kilo newton
L/150	-	Finale deflection at failure
L/600	-	Deflection at the point where nonlinearity begins
LL	-	Liquid limit
M	-	Molarity
M30, 50	-	Different grade of concrete mix
MDD	-	Maximum dry density
Mg	-	Magnesium
MgO	-	Magnesium oxide
MnO	-	Manganese oxide
MPa	-	Mega pascal
Mv	-	Coefficient of volume compressibility
n	-	degree of polycondensation
Na	-	Sodium
N-A-S-H	-	Sodium aluminosilicate hydrate
Na_2O	-	Sodium oxide
NaOH	-	Sodium hydroxide
Na_2OSiO_3	-	Sodium silicate
NFA	-	Neyveli fly ash
OH-	-	hydroxide ion
OH-(aq)	-	soluble hydroxide
OMC	-	Optimum moisture content
Pc	-	preconsolidation pressure
PE	-	Polyethylene
PH	-	Potential of Hydrogen
PI	-	Plasticity index
PL	-	Plastic limit
PP	-	Polypropylene
Rb_2O	-	Rubidium oxide
RHA	-	Rice husk ash
RG	-	Red gypsum
S1	-	light brown Kaolin Clay

S2	-	Marine clay
SEM	-	Scanning electron microscopy
Si	-	Silicon
SiO_2	-	Silicon dioxide
SO_3	-	Sulfite
SrO	-	Strontium oxide
UCS	-	Unconfined compressive strength
USA	-	United State of America
UTHM	-	University Tun Hussein Onn Malaysia
TiO_2	-	Titanium dioxide
Tm_2O_3	-	Thulium oxide
V_2O_5	-	vanadium Pentoxide
Y_2O_3	-	Yttrium oxide
ZnO	-	Zinc oxide
ZrO_2	-	Zirconium oxide

LIST OF APPENDICES

REFERENCES

Abdullah, H. H., Shahin, M. A., & Sarker, P. (2017). Stabilisation of Clay with Fly-Ash Geopolymer Incorporating GGBFS. In *Proceedings of the second Proceedings of the Second World Congress on Civil, Structural and Environmental Engineering (CSEE'17)* (pp. 1-8).

Abdullah, M. M. A., Hussin, K., Bnhussain, M., Ismail, K. N., & Ibrahim, W. M. W. (2011). Mechanism and chemical reaction of fly ash geopolymer cement-a review. *Int. J. Pure Appl. Sci. Technol*, *6*(1), 35-44.

Abdullah, M. S., Ahmad, F., & Mustafa Al Bakri, A. M. (2015). Geopolymer Application in Soil: A Short Review. In *Applied Mechanics and Materials* (Vol. 754, pp. 378-381). Trans Tech Publications.

Ahmad, F., Bateni, F., & Azmi, M. (2010). Performance evaluation of silty sand reinforced with fibers. *Geotextiles and Geomembranes*, *28*(1), 93-99.

Akbulut, S., Arasan, S., & Kalkan, E. (2007). Modification of clayey soils using scrap tire rubber and synthetic fibers. *Applied Clay Science*, *38*(1-2), 23-32.

Ali, M. K., Abu-Tair, A. I., Kinuthia, J. M., & Babecki, R. (2015). Self-healing and strength development of geopolymer concrete made with Waste by products.

Al Bakri, A. M., Kamarudin, H., Bnhussain, M., Nizar, I. K., Rafiza, A. R., & Izzat, A. M. (2011). Chemical Reactions in the Geopolymerisation Process Using Fly Ash–Based Geopolymer: A Review. *Australian Journal of Basic and Applied Sciences*, *5*(7), 1199-1203.

Alsafi, S. (2017). *Gypseous soil stabilization by alkaline activation method*. (Doctoral dissertation), Faculty of Engineering, UPM

American Society for Testing and Materials. (2012). Standard Test Method for Laboratory flexural strength test D 16359.

American Society for Testing and Materials. (1975). Standard Test Method for Laboratory indirect tensile test (Brazilian tests) D3379.

Ansu, T., Kumar, K., Tandon, L. & Prahash, OM. (2015) Effect of fly ash on the engineering properties of soil. International Journal of Advances in Mechanical and Civil Engineering, ISSN: 2394-2827 Volume-2, Issue-3, pp.16-18.

Astrom, L. (2016). Shedding of synthetic microfibers from textiles. *University of Gotherburg*.

Babu, V. R., Niveditha, K., & Babu, B. R. (2016). Stabilization of black cotton soil with sand and cement as a subgrade pavement. *International Journal of Civil Engineering and Technology, 7 (2)*, 341-351.

Baghini, M. S., & Ismail, A. (2015). Short-term Effects of Applying Carboxylated Styrene Butadiene Emulsion-Portland Cement Mixture on Road Base Construction. *Journal of Applied Sciences*, *15*(11), 1266-1277.

Bandyopadhyay, K. Bhattacharjee, S. (2010). Comparative Study Between Laboratory and Field CBR by DCP and IS Method. Indian Geotechnical Conference – 2010, GEO*trendz* December 16–18, 2010 IGS Mumbai Chapter & IIT Bombay.

Bergado, D. T., Ruenkrairergsa, T., Taesiri, Y., & Balasubramaniam, A. S. (1999). Deep soil mixing used to reduce embankment settlement. *Proceedings of the Institution of Civil Engineers-Ground Improvement*, *3*(4), 145-162.

Bhanumathidas, N., & Kalidas, N. (2005). Sustainable Development through use of Fly Ash. In *Keynote Paper presented at National Seminar on Building Materials & Technology for Sustainable Development, Ahmadabad*.

Bouzoubaa, N., & Fournier, B. (2003). Optimization of fly ash content in concrete: Part I: Non-air-entrained concrete made without superplasticizer. *Cement and Concrete Research*, *33*(7), 1029-1037.

British standard (1990) 1377-2. Standard Test Method for Laboratory Determination of Atterberg limits, soil particle density and soil particle size distribution.

British standard (1990) 1377-4. Standard Test Method for Laboratory standard proctor compaction test and California bearing capacity test.

British standard (1990) 1377-5. Standard Test Method for Laboratory one dimensional consolidation test.

British standard (1990) 1377-7. Standard Test Method for Laboratory Determination of Unconfined compressive strength test.

Brooks, R. M. (2009). Soil stabilization with fly ash and rice husk ash. *International Journal of Research and Reviews in Applied Sciences*, *1*(3), 209-217.

Chao, Y., Songyu, L., & Yongfeng, D. (2015). Experimental research for the application of mining waste in the trench cutting remixing deep wall method. *Advances in Materials Science and Engineering*, *2015*.

Chaple, P. M., & Dhatrak, A. I. (2013). Performance of coir fiber reinforced clayey soil. *The International Journal of Engineering and Science*, *2*(4), 54-64.

Chaudhary, M., Srivastava, V., & Agarwal, V. (2014). Effect of waste low density polyethylene on mechanical properties of concrete. *Journal of Academia and Industrial Research (JAIR) Volume*, *3*, 123-126.

Chen, L., & Lin, D. F. (2009). Stabilization treatment of soft subgrade soil by sewage sludge ash and cement. *Journal of Hazardous Materials*, *162*(1), 321-327.

Chithiraputhiran, S. R. (2012). *Kinetics of Alkaline Activation of Slag and Fly ash-Slag Systems*. Arizona State University.

Chore, H. S., & Vaidya, M. K. (2015). Strength characterization of fiber reinforced cement–fly ash mixes. *International Journal of Geosynthetics and Ground Engineering*, *1*(4), 30.

Coates, J. (2000). Interpretation of infrared spectra, a practical approach. *Encyclopedia of analytical chemistry*.

Consoli, N. C., Vendruscolo, M. A., Fonini, A., & Dalla Rosa, F. (2009). Fiber reinforcement effects on sand considering a wide cementation range. *Geotextiles and Geomembranes*, *27*(3), 196-203.

Consoli, N. C., de Moraes, R. R., & Festugato, L. (2011). Split tensile strength of monofilament polypropylene fiber-reinforced cemented sandy soils. *Geosynthetics International*, *18*(2), 57-62.

Correia, A. A., Oliveira, P. J. V., & Custódio, D. G. (2015). Effect of polypropylene fibers on the compressive and tensile strength of a soft soil, artificially stabilized with binders. *Geotextiles and Geomembranes*, *43*(2), 97-106.

Criado, M., Fernández-Jiménez, A., De La Torre, A. G., Aranda, M. A. G., & Palomo, A. (2007). An XRD study of the effect of the SiO2/Na2O ratio on the alkali activation of fly ash. *Cement and concrete research*, *37*(5), 671-679.

Cristelo, N., Glendinning, S., & Teixeira Pinto, A. (2011). Deep soft soil improvement by alkaline activation. *Proceedings of the Institution of Civil Engineers-Ground Improvement*, *164*(2), 73-82.

Cristelo, N., Glendinning, S., Miranda, T., Oliveira, D., & Silva, R. (2012a). Soil stabilization using alkaline activation of fly ash for self-compacting rammed earth construction. *Construction and Building Materials*, *36*, 727-735.

Cristelo, N., Glendinning, S., Fernandes, L., & Pinto, A. T. (2012b). Effect of calcium content on soil stabilization with alkaline activation. *Construction and Building Materials*, *29*, 167-174.

Cristelo, N., Glendinning, S., Fernandes, L., & Pinto, A. T. (2013a). Effects of alkaline-activated fly ash and Portland cement on soft soil stabilization. *Acta Geotechnica*, *8*(4), 395-405.

Cristelo, N., Soares, E., Rosa, I., Miranda, T., Oliveira, D. V., Silva, R. A., & Chaves, A. (2013b). Rheological properties of alkaline activated fly ash used in jet grouting applications. *Construction and Building Materials*, *48*, 925-933.

Cristelo, N., Cunha, V. M., Dias, M., Gomes, A. T., Miranda, T., & Araújo, N. (2015). Influence of discrete fiber reinforcement on the uniaxial compression response and seismic wave velocity of a cement-stabilized sandy-clay. *Geotextiles and Geomembranes*, *43*(1), 1-13.

Das, S. K., & Parhi, P. S. (2013). Stabilization of expansive soil using alkali activated fly ash. In *Proceeding of Indian Geotechnical Conference* (pp. 22-24).

Davidovits, J. (1991). Geopolymers: inorganic polymeric new materials. *Journal of Thermal Analysis and calorimetry*, *37*(8), 1633-1656.

Davidovits, J. (1993). Geopolymer cements to minimize carbon-dioxide greenhouse-warming. *Ceram. Trans.*, *37*, 165-182.

Davidovits, J. (1994, October). Properties of geopolymer cements. In *First international conference on alkaline cements and concretes* (Vol. 1, pp. 131-

149). Kiev State Technical University, Ukraine: Scientific Research Institute on Binders and Materials.

Davidovits, J. (2013). Geopolymer cement. *A review. Geopolymer Institute, Technical papers*, *21*, 1-11.

Davidovits, J. (2015). Geopolymer Chemistry and Applications 4th edition. Book, pp:1-20. Published by: Institut Géopolymère 16 rue Galilée F-02100. France.

Deb, K., & Narnaware, Y. K. (2015). Strength and Compressibility Characteristics of Fiber-Reinforced Subgrade and their Effects on Response of Granular Fill-Subgrade System. *Transportation in Developing Economies*, *1*(2), 1.

Deb, T., & Pal, S. K. (2014). Effect of fly ash on geotechnical properties of local soil-fly ash mixed samples. *International Journal of Research in Engineering and Technology*, *3*(5), 507-516.

Duan, J. X., Li, I, Lu, Z. Y. & Liao, Q. L. (2014). First principles study on the polycondensation of geopolymer gel. *Journal of Synthetic Crystals 43(9)*, pp.2416-2423

Duxson, P., Provis, J. L., Lukey, G. C., Mallicoat, S. W., Kriven, W. M., & Van Deventer, J. S. (2005). Understanding the relationship between geopolymer composition, microstructure and mechanical properties. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *269*(1-3), 47-58.

Duxson, P. (2006). *The structure and thermal evolution of metakaolin geopolymers* (Doctoral dissertation).

Duxson, P., Fernández-Jiménez, A., Provis, J. L., Lukey, G. C., Palomo, A., & van Deventer, J. S. (2007). Geopolymer technology: the current state of the art. *Journal of materials science*, *42*(9), 2917-2933.

Eberemu, A. O. (2011). Consolidation properties of compacted lateritic soil treated with rice husk ash. *Geomaterials*, *1*(03), 70.

Ethios Enviro Solution. Private Limited. Ahmedabad, Gujarat.

Fang, Y. S., Chung, Y. T., Yu, F. J., & Chen, T. J. (2001). Properties of soil-cement stabilized with deep mixing method. *Proceedings of the Institution of Civil Engineers-Ground Improvement*, *5*(2), 69-74.

Fasihnikoutalab, M. H., Asadi, A., Huat, B. K., Westgate, P., Ball, R. J., & Pourakbar, S. (2016). Laboratory-scale model of carbon dioxide deposition for soil stabilization. *Journal of Rock Mechanics and Geotechnical Engineering*, *8*(2), 178-186.

Fasihnikoutalab, M. H., Pourakbar, S., Ball, R. J., & Huat, B. K. (2017). The effect of olivine content and curing time on the strength of treated soil in presence of potassium hydroxide. *International Journal of Geosynthetics and Ground Engineering*, *3*(2), 12.

Feely, R. A., Sabine, C. L., Lee, K., Berelson, W., Kleypas, J., Fabry, V. J., & Millero, F. J. (2004). Impact of anthropogenic CO2 on the CaCO3 system in the oceans. *Science*, *305*(5682), 362-366.

Fernández-Jiménez, A., Palomo, A., Sobrados, I., & Sanz, J. (2006). The role played by the reactive alumina content in the alkaline activation of fly ashes. *Microporous and Mesoporous materials*, *91*(1-3), 111-119.

Garc a-Gaines, R. A., & Frankenstein, S. (2015). *USCS and the USDA Soil Classification System: Development of a Mapping Scheme* (No. ERDC/CRREL-TR-15-4). ENGINEER RESEARCH AND DEVELOPMENT CENTER HANOVER NH COLD REGIONS RESEARCH AND ENGINEERING LAB.

Grdic, Z. J., Curcic, G. A. T., Ristic, N. S., & Despotovic, I. M. (2012). Abrasion resistance of concrete micro-reinforced with polypropylene fibers. *Construction and Building Materials*, *27*(1), 305-312.

Halsted, G. E., Adaska, W. S., & McConnell, W. T. (2008). Guide to cement-modified soil (CMS).

Hejazi, S. M., Sheikhzadeh, M., Abtahi, S. M., & Zadhoush, A. (2012). A simple review of soil reinforcement by using natural and synthetic fibers. *Construction and building materials*, *30*, 100-116.

Hendriks, C. A., Worrell, E., De Jager, D., Blok, K., & Riemer, P. (1998, August). Emission reduction of greenhouse gases from the cement industry. In *Proceedings of the fourth international conference on greenhouse gas control technologies* (pp. 939-944).

Hong, Y., Wu, X., & Zhang, P. (2017). Construction Technology and Mechanical Properties of a Cement-Soil Mixing Pile Reinforced by Basalt Fiber. *Advances in Materials Science and Engineering*, *2017*.

Hesham, A. H. I. (2006). Treatment and improvement of the geotechnical properties of different soft fine-grained soils using chemical stabilization. *Dissertation zur Erlangung des akademischen Gradesdoctor rerum naturalium, Mathematisch-Naturwissenschaftlich-Technischen Fakultät der Martin-Luther-Universität Halle-Wittenberg*, 1-121.

Jafer, H. M., Obaid, H. A., & Hadi, A. H. (2013). Stabilization of soft soil subgrade layers by using lime-micro silica fume mixture. *Euphrates Journal of Agriculture Science*, *5*, 44-53.

Jamsawang, P., Voottipruex, P., & Horpibulsuk, S. (2014). Flexural strength characteristics of compacted cement-polypropylene fiber sand. *Journal of Materials in Civil Engineering*, *27*(9), 04014243.

Jamshidi, R., Towhata, I., Ghiassian, H., & Tabarsa, A. R. (2010). Experimental evaluation of dynamic deformation characteristics of sheet pile retaining walls with fiber reinforced backfill. *Soil Dynamics and Earthquake Engineering*, *30*(6), 438-446.

Jawad, I. T., Taha, M. R., Majeed, Z. H., & Khan, T. A. (2014). Soil stabilization using lime: Advantages, disadvantages and proposing a potential alternative. *Research Journal of Applied Sciences, Engineering and Technology*, *8*(4), 510-520.

Jeevanantham, V., Jayashree, J., & Magudeaswaran, P. (2016). Influence of Fly Ash in Strength Characteristics of Cohesive Soils. *Technology*, *7*(6), 67-72.

Jia, J. (2010). *Melt spinning of continuous filaments by cold air attenuation*. Georgia Institute of Technology.

Jiesheng, L., Juan, Z., & Lin, X. (2014). Deformation and Strength Characteristics of Sisal Fibrous Soil. *EJGE*, *19*.

Joshi, R. C., & Lohtia, R. P. (1993). Types and Properties of Fly Ash. *Mineral Admixtures in Cement and Concrete*, *4*, 118-157.

Kakooei, S., Akil, H. M., Jamshidi, M., & Rouhi, J. (2012). The effects of polypropylene fibers on the properties of reinforced concrete structures. *Construction and Building Materials*, *27*(1), 73-77.

Kalaivani, M., (2015). Experimental investigation for flexural strength of fly ash concrete with addition of alkaline activator. *Journal of Engineering and*

Applied Sciences, VOL. 10, NO. 11, JUNE 2015. ISSN 1819-6608, pp.4838-4841.

Kalantari, B., Huat, B. B., & Prasad, A. (2010). Effect of polypropylene fibers on the California Bearing Ratio of air cured stabilized tropical peat soil. *Am. J. Engg. & Applied Sci*, *3*(1), 1-6.

Kalita, T., Saikia, A., & Das, B. (2017). Effect of Fly-ash on Strength Behavior of Clayey Soil.

Karimi, K., & Taherzadeh, M. J. (2016). A critical review of analytical methods in pretreatment of lignocelluloses: composition, imaging, and crystallinity. *Bioresource technology*, *200*, 1008-1018.

Kazemian, S., & Huat, B. B. (2009). Assessment and comparison of grouting and injection methods in geotechnical engineering. *European Journal of Scientific Research*, *27*(2), 234-247.

Khalid, N., Sidek, N & Arshad, M. F (2013). The California Bearing Ratio (Cbr) Value Of Road Sub-Base Aggregate Mixed With Bottom Ash *Malaysian Journal of Civil Engineering 25 Special Issue (1):112-121 (2013)*

Kim, M. O., & Bordelon, A. C. (2017). Age-dependent properties of fiber-reinforced concrete for thin concrete overlays. *Construction and Building Materials*, *137*, 288-299.

KS, N., Chew, Y. M., Osman, M. H., & SK, M. G. (2015). Estimating maximum dry density and optimum moisture content of compacted soils. *International Conference on Advances in Civil and Environmental Engineering 2015.*

Kumar, A., Marathe, S., Vikram, R., Shenoy, N., Bhat, V. L., & Venkatesh, A. (2015). Stabilization of Lithomargic Soil Using Alkali Activated Fly-Ash with GGBS.

Lee, S., Van Riessen, A., & Chon, C. M. (2016). Benefits of Sealed-Curing on Compressive Strength of Fly Ash-Based Geopolymers. *Materials*, *9*(7), 598.

Lee, W. K. W., & Van Deventer, J. S. J. (2002). The effects of inorganic salt contamination on the strength and durability of geopolymers. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *211*(2-3), 115-126.

Lowe, R. D. (2012). *Pozzolanic properties of biomass fly ash* (Master Thesis, Clemson University).

Lyon, R. E. (1996). *Fire Response of Geopolymer Structural Composites* (No. DOT/FAA/AR-TN95/22). Federal aviation administration washington dc office of aviation research.

Maddah, H. A. (2016). Polypropylene as a promising plastic: A review. *American Journal of Polymer Science*, *6*(1), 1-11.

Madhavi, T. C., Raju, L. S., & Mathur, D. (2014). Polypropylene fiber reinforced concrete-a review. *International journal of emerging technology and advanced engineering*, *4*(4), 114-119.

Mahajan, S. M., & Parbat, D. K. (2015). Effects of Fly ash on Engineering Properties of BC Soil. *International Journal of Engineering Science and Research*, *1*(5).

Maitz, M. F. (2015). Applications of synthetic polymers in clinical medicine. *Biosurface and Biotribology*, *1*(3), 161-176.

Malekzadeh, M., & Bilsel, H. (2012). Effect of polypropylene fiber on mechanical behavior of expansive soils. *EJGE*, *17*, 55-63.

Mali, S. & Singh, B. (2013). Strength behavior of sand reinforced with glass fibers. *SAITM Research Symposium on Engineering Advancements 2013 (SAITM – RSEA 2013)*

Martins, A. P. S., Silva, F. A., & Toledo Filho, R. D. (2015). Mechanical behavior of self-compacting soil-cement-sisal fiber composites. In *Key Engineering Materials* (Vol. 634, pp. 421-432). Trans Tech Publications.

McLellan, B. C., Williams, R. P., Lay, J., Van Riessen, A., & Corder, G. D. (2011). Costs and carbon emissions for geopolymer pastes in comparison to ordinary Portland cement. *Journal of cleaner production*, *19*(9-10), 1080-1090.

Memon, F. A., Nuruddin, M. F., Demie, S., & Shafiq, N. (2011). Effect of curing conditions on strength of fly ash-based self-compacting geopolymer concrete. *World Acad Sci Eng Technol*, *80*, 860-863.

Mir, B. A. (2015). Some studies on the effect of fly ash and lime on physical and mechanical properties of expansive clay. *IJCE*, *13*, 203-212.

Moghal, A. A. B. (2017). State-of-the-Art Review on the Role of Fly Ashes in Geotechnical and Geoenvironmental Applications. *Journal of Materials in Civil Engineering*, *29*(8), 04017072.

Mohamed, R. (2006). Effect of polypropylene fibers on the mechanical properties of normal concrete. *Journal of Engineering Sciences, Assiut University*, *34*(4), 1049-1059.

Morgan, P. W. (1981). Brief history of fibers from synthetic polymers. *Journal of Macromolecular Science—Chemistry*, *15*(6), 1113-1131.

Mustapha, A. M. (2008). Bamboo as soil reinforcement: A laboratory trial. *Leonardo Journal of Sciences*, *13*, 69-77.

Nemati, K. M. (2013). Progress in concrete technology—Fiber reinforced concrete. *Univ. of Washington Courses, 〈 http://courses. washington. edu/cm425/frc. pdf〉(Sep. 5, 2013)*.

Ola, S. A. (1989). Stabilization of lateritic soils by extensible fiber reinforcement. *Engineering Geology*, *26*(2), 125-140.

Ondova, M., Stevulova, N., & Meciarova, L. (2013). The potential of higher share of fly ash as cement replacement in the concrete pavement. *Procedia Engineering*, *65*, 45-50.

Padhye, R. D., & Deo, N. S. (2016). Cement replacement by fly ash in concrete. *International Journal of Engineering Research*, *5*, 60-62.

Palomo, A., & Fernández-Jiménez, A. (2011, May). Alkaline activation, procedure for transforming fly ash into new materials. Part I: Applications. In *World of Coal Ash (WOCA) Conference* (pp. 1-14).

Palomo, A., Krivenko, P., Garcia-Lodeiro, I., Kavalerova, E., Maltseva, O., & Fernández-Jiménez, A. (2014). A review on alkaline activation: new analytical perspectives. *Materiales de Construcción*, *64*(315), 022.

Parhi, P. S. (2014). *Stabilization of expansive soils using alkali activated fly ash* (Master Thesis).

Patel, M. A. & Dr. Patel, H. S. (2012). A review on effect of stabilizing agent for stabilization of weak soil. *Civil and Environmental Research ISSN 2222-1719 (Paper) ISSN 2222-2863 (Online) Vol 2, No.6*.

Paul, J. V. & Sneha, A. R. M. (2016). Effect of random inclusion of bamboo fibers on strength behavior of fly ash treated black cotton soil. *International Journal of Civil Engineering and Technology (IJCIET). Volume 7,* Issue 5, September-October 2016, pp:153–160, Article ID: IJCIET_07_05_017. ISSN Print: 0976-6308 and ISSN Online: 0976-6316.

Pourakbar., S. (2015) *The use of alkali- activated palm oil fuel ash reinforced by microfibers in deep mixing method*. (Doctoral dissertation), Faculty of Engineering, UPM.

Pourakbar, S., Asadi, A., Huat, B. B., Cristelo, N., & Fasihnikoutalab, M. H. (2016). Application of alkali-activated agro-waste reinforced with wollastonite fibers in soil stabilization. *Journal of Materials in Civil Engineering*, *29*(2), 04016206.

Prasad, S. K. (2015). Index properties of soil. *College of Engineering, Mysore*.

Provis, J. L. & Van Devender, J. S. L. (2014). Alkali activated material. State of the art report, Springer publishing. ISBN 978-94-007-7671-5.

Ramesh, H. N., Krishna, K. V., & Mamatha, H. V. (2010, December). Effect of lime-coir fiber on geotechnical properties of Black Cotton Soil. In *Indian Geotechnical Conf.–2010* (pp. 487-490).

Ramujee, K. (2013). Strength properties of polypropylene fiber reinforced concrete. *International Journal of Innovative Research in Science, Engineering and Technology*, *2*(8), 3409-3413.

Ranjbar, N., Mehrali, M., Behnia, A., Pordsari, A. J., Mehrali, M., Alengaram, U. J., & Jumaat, M. Z. (2016). A comprehensive study of the polypropylene fiber reinforced fly ash based geopolymer. *PloS one*, *11*(1), e0147546.

Ratna, P. S. (2016). Performance of Recron-3s Fiber with Lime in Expansive Soil Stabilization. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN*, 2278-1684.

Rios, S., Cristelo, N., Miranda, T., Araújo, N., Oliveira, J., & Lucas, E. (2016). Increasing the reaction kinetics of alkali-activated fly ash binders for stabilization of a silty sand pavement sub-base. *Road Materials and Pavement Design*, *19*(1), 201-222.

Rivera-Gómez, C., Galán-Marín, C., & Bradley, F. (2014). Analysis of the influence of the fiber type in polymer matrix/fiber bond using natural organic polymer stabilizer. *Polymers*, *6*(4), 977-994.

Roy, A. (2014). Soil stabilization using rice husk ash and cement. *International Journal of Civil Engineering Research*, *5*(1), 49-54.

Ryu, G. S., Lee, Y. B., Koh, K. T., & Chung, Y. S. (2013). The mechanical properties of fly ash-based geopolymer concrete with alkaline activators. *Construction and Building Materials*, *47*, 409-418.

Sabat, A. K. (2012). Effect of polypropylene fiber on engineering properties of rice husk ash–lime stabilized expansive soil. *Electronic Journal of Geotechnical Engineering*, *17*, 651-660.

Safiuddin, M., Jumaat, M. Z., Salam, M. A., Islam, M. S., & Hashim, R. (2010). Utilization of solid wastes in construction materials. *International Journal of Physical Sciences*, *5*(13), 1952-1963.

Sagoe-Crentsil, K., & Weng, L. (2007). Dissolution processes, hydrolysis and condensation reactions during geopolymer synthesis: Part II. High Si/Al ratio systems. *Journal of materials science*, *42*(9), 3007-3014.

Sato, H., & Ogawa, H. (2009). Review on development of polypropylene manufacturing process. *Sumitomo Chemical Co., Ltda. Process & Production Technology Center. Fecha de consulta*, *12*.

Satpute Manesh, B., Wakchaure Madhukar, R., & Patankar Subhash, V. (2012). Effect of duration and temperature of curing on compressive strength of geopolymer concrete. *International Journal of Engineering and Innovative Technology (IJEIT) Volume*, *1*.

Seco, A., Ramirez, F., Miqueleiz, L., Urmeneta, P., García, B., Prieto, E., & Oroz, V. (2012). Types of waste for the production of pozzolanic materials–a review. In *Industrial Waste*. Intech.

Senapati, M. R. (2011). Fly ash from thermal power plants–waste management and overview. *Current science*, 1791-1794.

Shakor, P. N., & Pimplikar, S. S. (2011). Glass fiber reinforced concrete use in construction. *Int. J. Technol. Eng. Syst*, *2*(2).

ShashwatSharda, Singh, M. & Singh, S. (2016). A review on Properties of Fiber Reinforced Cement-based materials. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 13*, Issue 5 Ver. I (Sep. - Oct. 2016), pp.104-112.

Sherwood, P. (1993). Soil stabilization with cement and lime. State of the art review. *Technical Rep., Transport Research Laboratory, HMSO, London*.

Sivapullaiah, P. V., Prashanth, J. P., & Sridharan, A. (1996). Effect of fly ash on the index properties of black cotton soil. *Soils and foundations*, *36*(1), 97-103.

Škvára, F., Kopecký, L., Myšková, L., Šmilauer, V., Alberovska, L., & Vinšová, L. (2009). Aluminosilicate polymers–influence of elevated temperatures, efflorescence. *Ceramics–Silikáty*, *53*(4), 276-82.

Solanki, P., & Zaman, M. (2012). Microstructural and mineralogical characterization of clay stabilized using calcium-based stabilizers. In *Scanning electron microscopy*. In Tech.

Sobolev, K., Moini, M., Tabatabai, H., Titi, H. H., Pradoto, R., Kozhukhova, M., ... & Muzenski, S. (2017). *Class F Fly Ash Assessment for Use in Concrete Pavements* (No. WHRP 0092-15-10). Wisconsin Highway Research Program.

Soutsos, M., Boyle, A. P., Vinai, R., Hadjierakleous, A., & Barnett, S. J. (2016). Factors influencing the compressive strength of fly ash based geopolymers. *Construction and Building Materials*, *110*, 355-368.

Sukontasukkul, P., & Jamsawang, P. (2012). Use of steel and polypropylene fibers to improve flexural performance of deep soil–cement column. *Construction and Building Materials*, *29*, 201-205.

Sureban, V. (2011). Consolidation Characteristics of Fly Ash and Lime Treated Black Cotton Soil. In *Proc. of. Int. Conf. on recent Trends in Transportation, Environmental ands Civil Engineering* (pp. 49-52).

Tang, C., Shi, B., Gao, W., Chen, F., & Cai, Y. (2007). Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. *Geotextiles and Geomembranes*, *25*(3), 194-202.

Tang, C. S., Shi, B., & Zhao, L. Z. (2010). Interfacial shear strength of fiber reinforced soil. *Geotextiles and Geomembranes*, *28*(1), 54-62.

Tempest, B., Sanusi, O., Gergely, J., Ogunro, V., & Weggel, D. (2009, May). Compressive strength and embodied energy optimization of fly ash based geopolymer concrete. In *world of coal ash (WOCA) conference*.

Thomas, M. D. A. *Optimizing the use of fly ash in concrete*. Vol. 5420. Skokie, IL: Portland Cement Association, 2007. Timuran Engineering Sdn Bhd Malaysia.

Van Jaarsveld, J. G. S., Van Deventer, J. S. J., & Lukey, G. C. (2002). The effect of composition and temperature on the properties of fly ash-and kaolinite-based geopolymers. *Chemical Engineering Journal*, *89*(1-3), 63-73.

Timuran Engineering Sdn Bhd, Malaysia

Vickers, L., van Riessen, A., & Rickard, W. D. (2015). Precursors and additives for geopolymer synthesis. In *Fire-Resistant Geopolymers* (pp. 17-37). Springer, Singapore.

Wafa, F. F. (1990). Properties & applications of fiber reinforced concrete. *Engineering Sciences*, *2*(1).

Wallah, S., & Rangan, B. V. (2006). Low-calcium fly ash-based geopolymer concrete: Long-term properties.

Ward, C. R., & French, D. (2005). Relation between coal and fly ash mineralogy, based on quantitative X-ray diffraction methods. *World Coal Ash (WOCA), April*, 11-15.

Yilmaz, E. (2012). One-dimensional consolidation parameters of cemented paste backfills/parametry Jednowymiarowej Konsolidacji Podsadzki W Postaci Cementowej Pasty. *Gospodarka Surowcami Mineralnymi-Mineral Resources Management*, *28*(4), 29-45.

Zerfu, K., & Ekaputri, J. J. (2016). Review on Alkali-Activated Fly Ash Based Geopolymer Concrete. In *Materials Science Forum* (Vol. 841, pp. 162-169). Trans Tech Publications.

Zhang, M., Guo, H., El-Korchi, T., Zhang, G., & Tao, M. (2013). Experimental feasibility study of geopolymer as the next-generation soil stabilizer. *Construction and Building Materials*, *47*, 1468-1478.

Zumrawi, M. M., & Hamza, O. S. (2014). Improving the characteristics of expansive subgrade soils using lime and fly ash. *International Journal of Science and Research*, *3*(2), 1124-1129.

Zumrawi, M. M. (2015). Stabilization of Pavement Subgrade by Using Fly Ash Activated by Cement. *American Journal of Civil Engineering and Architecture*, *3*(6), 218-224.

Yahya, Z., Abdullah, M. M. A. B., Hussin, K., Ismail, K. N., Razak, R. A., & Sandu, A. V. (2015). Effect of solids-to-liquids, Na2SiO3-to-NaOH and curing temperature on the palm oil boiler ash (Si+ Ca) geopolymerizetion system. *Materials*, *8*(5), 2227-2242.